Flight State Estimation From Surface Surveillance

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Overview

- Problem statement
- Related work
- Flight state estimation algorithm
- Results for actual ASDE-X data
- Conclusion

Problem Statement

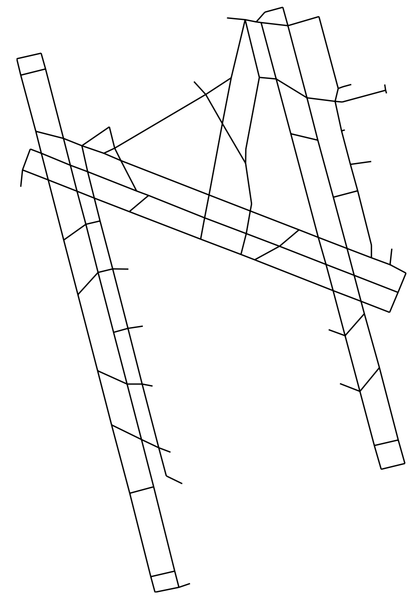
- Surface surveillance (SS) data provide accurate estimates labeled with aircraft ID of position, speed, heading and other data for aircraft on or above the airport surface or within several kilometers
- For some uses of the surface surveillance output, it is necessary to know the taxiway the aircraft occupies
  - Surface Management System (SMS) developed by NASA and others
  - Stand-Alone Event Detector and Predictor (SAEE) developed by NASA, the FAA and Metron Aviation
- Due to error in the position reported by SS, the nearest taxiway is not necessarily the one occupied by the aircraft
- *This paper addresses the problem of using the SS output to determine the taxiway occupied by the aircraft.*
  - Novel algorithm based on a multiple hypothesis Kalman filter
  - Results using actual ASDE-X output from Louisville International Airport

Related Work

- Vehicle navigation systems such as in portable Global Positioning System (GPS) units must determine a vehicle's road from noisy position data (map matching problem). Review in Quddus *et. al*. (2003).
  - Commonly use curve matching techniques
  - Scott and Drane (1994) propose using a Kalman filter on each road that the vehicle might be on, but there is no available reference giving either details of the approach or results.
  - Pyo, Shin, and Sung (2001) use an *ad hoc* application of Bayes's rule incorporating traffic rules to compute likelihoods of multiple hypotheses and use a Kalman filter to estimate bias
- In the airport surface domain, Meier (1999) uses a Kalman filter in which the target is constrained to move on an airport network
  - Multiple hypotheses represent different possible routes
  - Null hypothesis that the aircraft is not on the airport network
  - Interacting Multiple Model (IMM) algorithm to manage the hypotheses
  - Results presented for simulated data with Gaussian error

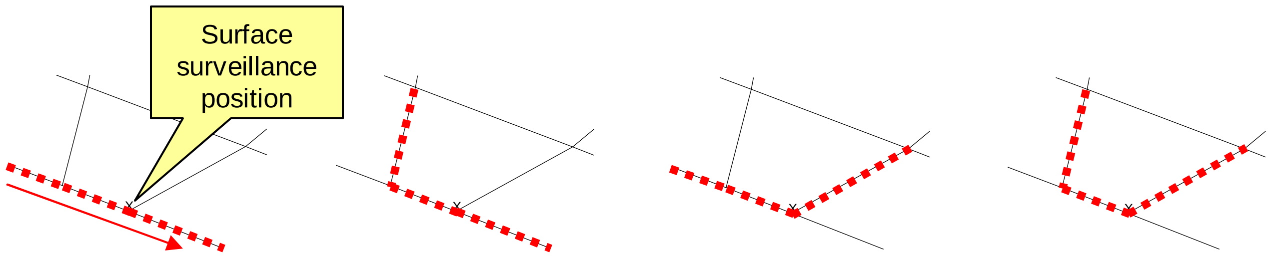
Model of Airport Movement Area

- We represent the pavement in the airport movement area as a two-dimensional graph consisting of nodes connected by line segments such that the line segments only intersect at nodes
- Nodes are also called intersections; line segments are called links
- We use a Kalman filter in which the target is constrained to move on a path of links
  - The accuracy of this assumption depends upon the width of the pavement
  - We do not apply our Kalman filter in ramp areas, where this assumption is invalid



The Hypotheses

- Each hypothesis has a path of links that the aircraft is assumed to be moving along
- As the target moves, a link sufficiently close to the current SS position may be added to the end of a path
- If the reported position is sufficiently close to an intersection, then there will be multiple hypotheses, one for each path that the aircraft may take through the intersection
- A path may include possible links in the past and future as well as for the current estimate
- A link is removed from a path when it is sufficiently far from the expected position for that hypothesis
- An hypothesis is pruned when it is no longer consistent with current SS reports
- Examples of hypothesized paths:



The Kalman Filter

- Each hypothesis has a separate Kalman filter tracking the aircraft state probability distribution given that hypothesis and the observations processed
- The Kalman filter state is position and velocity *on the hypothesized path*
- All hypotheses use the same constant velocity motion model
- No interaction between the hypotheses, although hypotheses may be merged if their paths are the same and their distributions are sufficiently close
- The algorithm also computes the probability that each hypothesis is true, given the observations processed

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Point Estimates

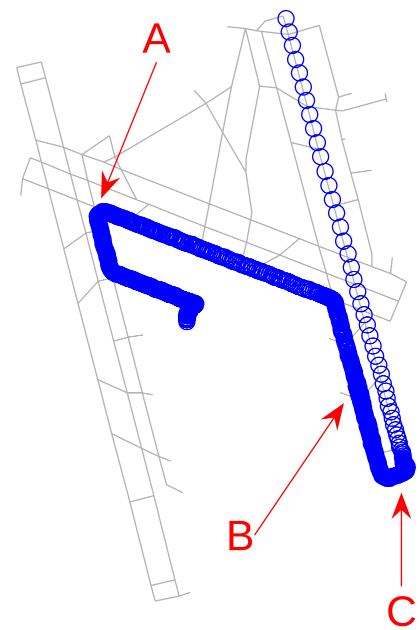
- Kalman filter produces probability density function for the aircraft state, but in most applications a specific estimate is required
- We use the expected state of the most likely hypothesis, which gives the position – including link – and speed
- Once the link is estimated, there are only two possible headings for the aircraft
  - The choice is usually determined from the sign of the expected path velocity
  - When the speed is small, the sign of the velocity is unstable, so the SS heading is used to choose the link direction
- The confidence in the estimate is computed
  - If the confidence is too low, wait for additional information to clarify the situation

The Test Data

- ASDE-X data from Louisville International Airport in December 2004
  - ASDE-X system installed in 2004 and will be fully certified later in 2005
  - Quality of the ASDE-X output has noticeably improved since summer 2004 due to tuning of the sensors, but this has leveled off; so we assume that the December 2004 data to be very close to production quality
- Ground truth data for aircraft positions is not available, so rigorous testing cannot be conducted. Instead, we have manually compared our estimates with the ASDE-X data for a large number of flights to confirm that our estimates seem reasonable.

Example Track

- This figure shows the ASDE-X position estimates over time for a departing aircraft with each circle denoting one position estimate
  - ASDE-X reports estimates once per second, so individual circles cannot be distinguished until the aircraft is nearly airborne
  - Positions in the ramp area are shown but not processed by our algorithm
- At the scale of this figure, the estimates obtained by the algorithm presented here cannot be distinguished from the ASDE-X positions, so we will show closeups at the locations labeled A, B, and C



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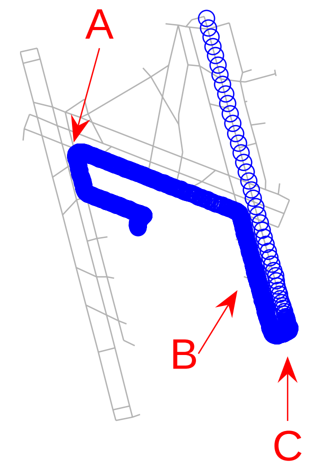
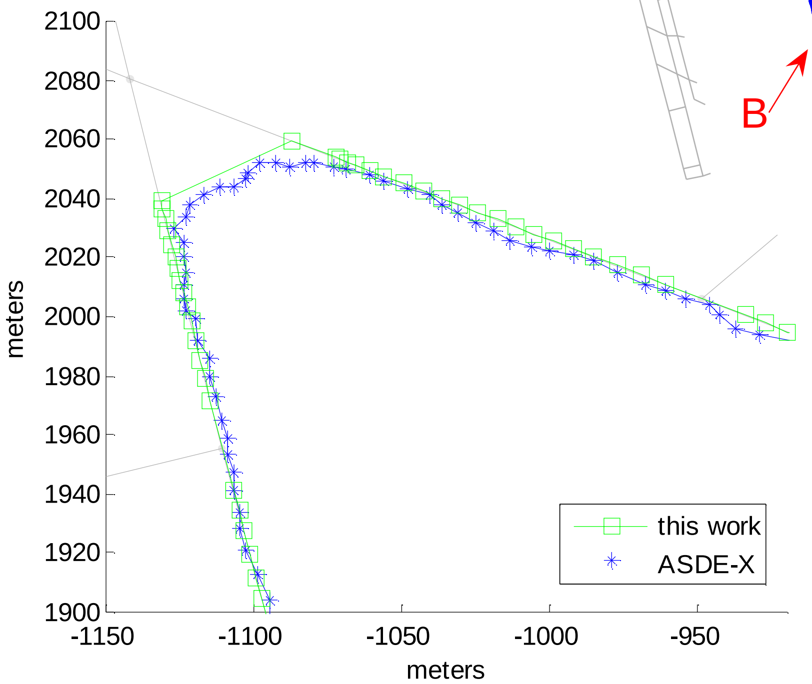
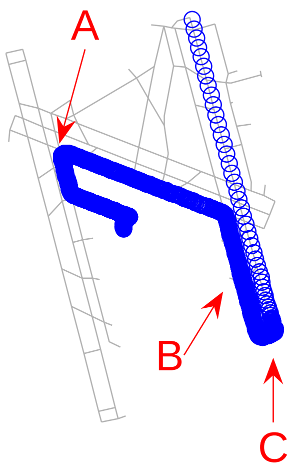
Closeup at Location A

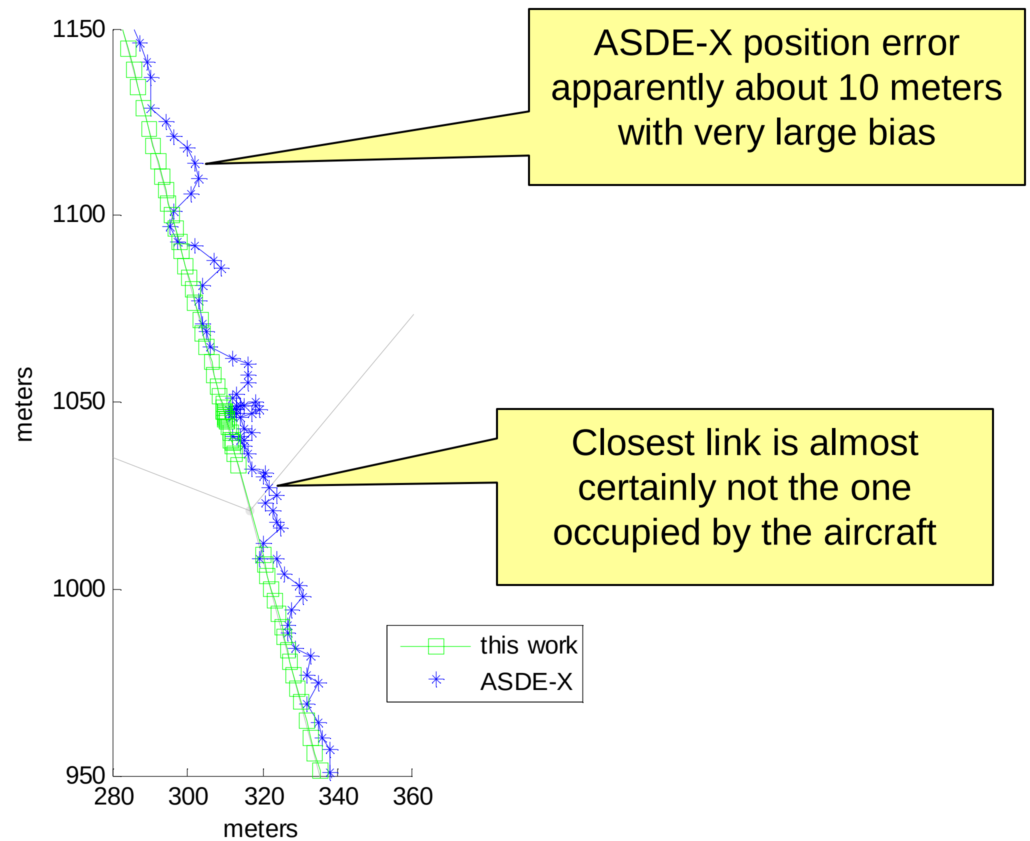
- ASDE-X positions tend to be very accurate, apparently within 2-3 meters, but the error seems to have significant bias
- Only our estimates with high confidence are shown
- Our algorithm is not able to determine the link when aircraft is near an intersection
- Where the aircraft turns the corner, there is significant width to the pavement, so assumption that the aircraft must be on our link network is invalid



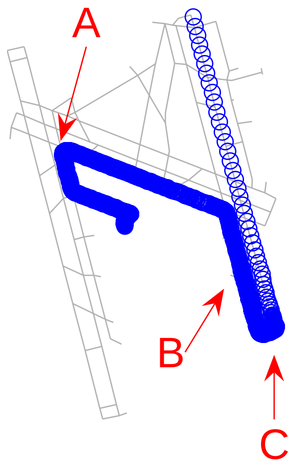


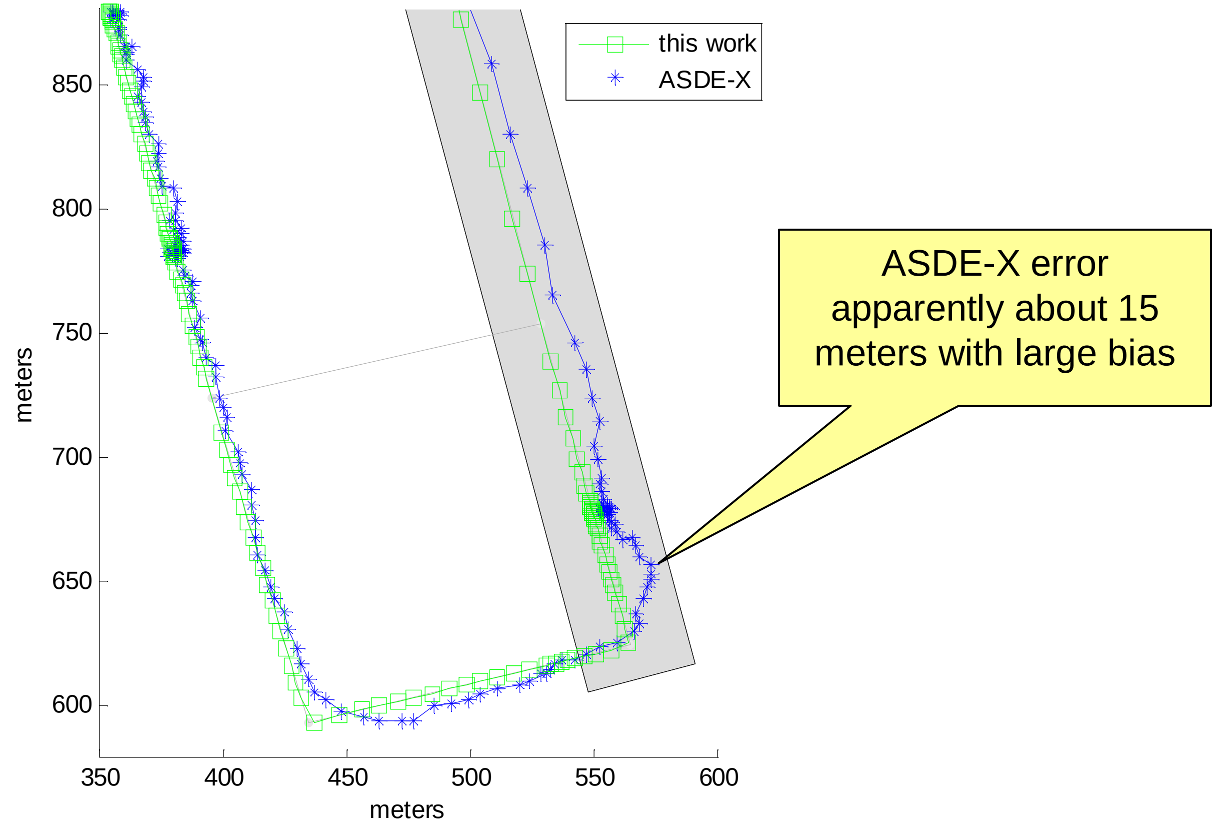
Closeup at Location B





Closeup at Location C





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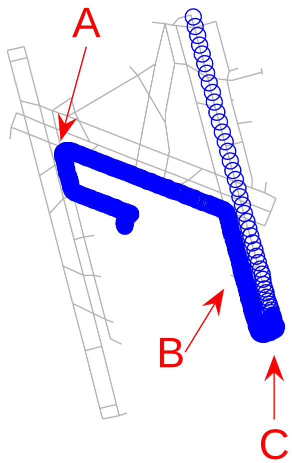
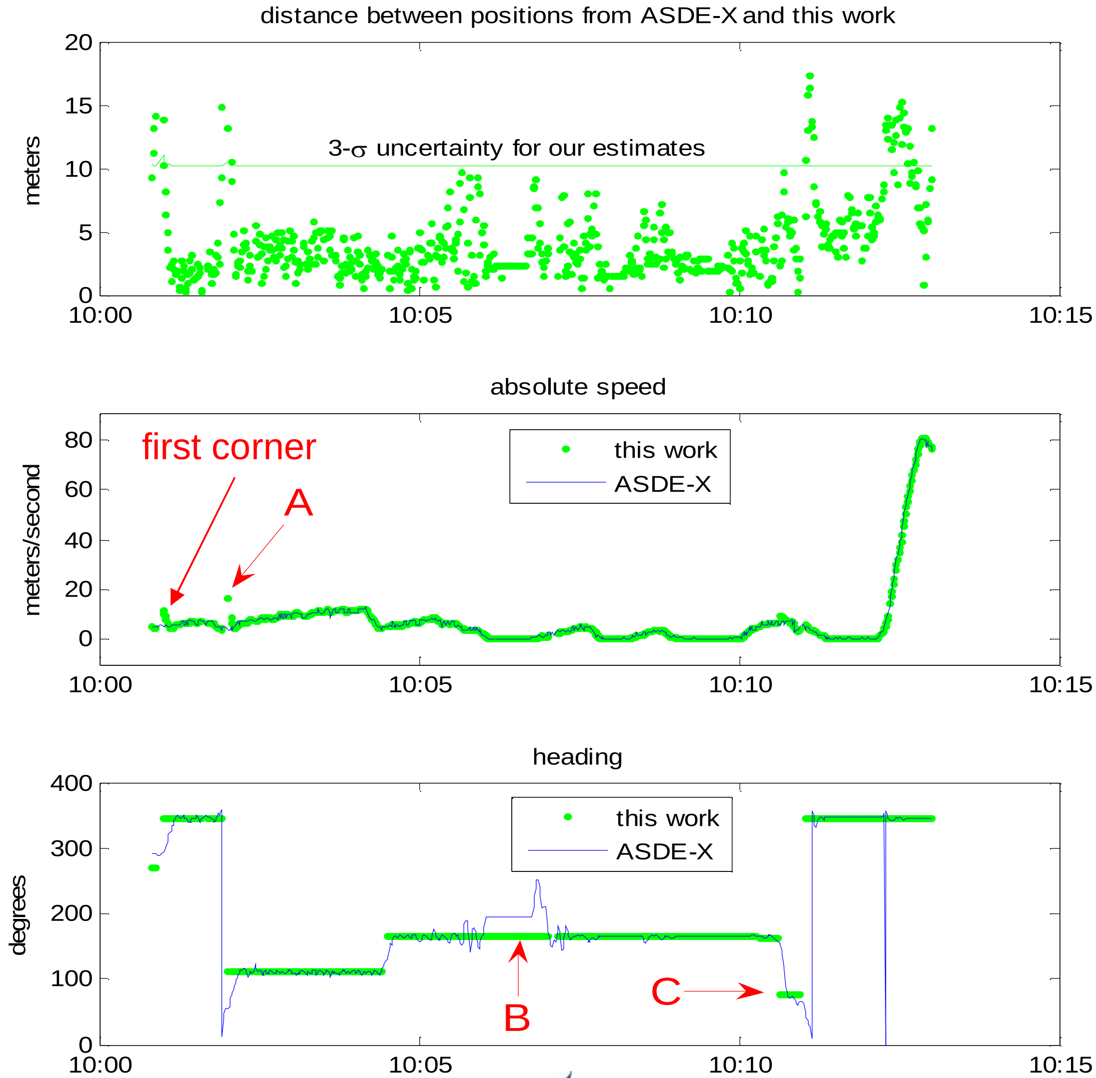
Comparison of Positions, Speeds, and Headings





Conclusion

- *The primary benefit provided by our algorithm is that it estimates which link the aircraft is on and computes the confidence in that estimate.*
  - Aids the surface trajectory predictions in surface management decision support tools and surface event prediction tools
  - Constraining the position estimates to the taxiway and runway links improves the heading estimates in many cases, which will help in presenting meaningful information to controllers
- To improve our estimates when the aircraft turns a corner, we have tried adding more links to the taxiway network
  - Increases the number of intersections, which means the estimate confidence is low more often
  - Occasionally results in a large increase in the number of hypotheses
  - We need to be more judicious in adding links and in creating hypothesized paths